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## FINAL TECHNICAL REPORT

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Title: Wave Dynamics and Transport in the Stratosphere

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## A. Introduction

This grant supported a combined program of theoretical modeling, numerical simulation, and observational data analysis designed to elucidate the dynamics of large scale wave motions in the stratosphere and mesosphere and their roles in transport of momentum, heat, vorticity, and trace chemical substances. This research is being continued under a new NASA grant (NAGW-622) with the same title as this grant.

## B. Research Summary

Our research under support of this grant concentrated on three major aspects of middle atmosphere dynamics: the role of gravity wave breaking in the momentum budget of the mesosphere, the roles of planetary waves in the transport of long lived chemical tracers, and the mixing and dispersion caused by planetary "wave-breaking in the winter hemisphere. We also began work on a new initiative to develop a middle atmosphere version of the NCAR spectral general circulation model (with partial support from the NSF).

### (i) The momentum budget of the mesosphere.

Lindzen's parameterization for the drag and diffusion due to gravity wave breaking in the mesosphere was tested in a mechanistic model by graduate student Xun Zhu and the PI. In this study a gravity wave source was assumed that consisted of a broad wave spectrum in which individual components were influenced by the breaking of other components. When compared to earlier studies, these results indicated that the wave drag on the mean flow was spread out over a deeper layer of the atmosphere and was smoother than in models based on a limited wave spectrum (Holton and Zhu, 1984).

Ray theory was used by Postdoctoral Research Associate N. Butchart and a colleague to demonstrate that the pattern of gravity wave drag can be drastically altered due to selective wave transmission during sudden warming events (Dunkerton and Butchart, 1984).

The role of selective transmission in altering the mean flow in the mesosphere and in possibly generating planetary wave disturbances in the mesosphere was investigated using our global semi-spectral model in two studies (Holton, 1983; 1984). It was shown that selective transmission may contribute importantly to the mesospheric cooling process often seen in conjunction with stratospheric warmings. It was also shown that zonally asymmetric gravity wave sources (e. g., topography) might produce zonally asymmetric wave drag fields that could excite stationary planetary waves in the mesosphere.

### (ii) Tracer Transport

Graduate student Ben Jou completed a doctoral thesis (Jou, 1984) in which he analyzed rapid poleward and downward ozone transport in association with a simulated sudden warming based on our global semi-spectral primitive equation model. He compared the traditional Eulerian diagnostics with the new "residual" circulation approach in order to understand the transport mechanisms in this model. The poleward ozone transport simulated in the model was very similar to that observed for the major warming of winter 1979, even though the wave, mean-flow model used does not include the "wave breaking" process currently in vogue as an explanation for the observed warmings.

Graduate student Peter Hess and the PI have completed work on a study of transport of long-lived chemical tracers in which an idealized beta-plane channel model was used to investigate the validity of certain proposed approaches to parameterizing the wave transport in 2-dimensional models by integrating a 3-d model explicitly and comparing the transport to that given by a 2-d parameterized version of the model. It was shown that the latter produced a satisfactory approximation of the zonal mean in the 3-d model only in the absence of sudden stratospheric warmings. This work has provided useful guidance on the limitations of 2-d transport models (Hess and Holton, 1985).

Insights into the dynamics of vertical transport in the stratosphere were employed by the PI (Holton, 1985) to develop a dynamically based parameterization for the vertical eddy transport coefficient required in 1-dimensional photochemical models. It was shown that the transport coefficient should depend on the chemical lifetime of the species being transported, with smaller coefficients required for shorter lived species. This formulation should prove very useful for perturbation studies carried out with 1-d models.

#### (iii) Planetary wave breaking

Following a suggestion by McIntyre, Postdoctoral Research Associate Neal Butchart examined the evolution of Ertel Potential Vorticity, ozone, and water vapor distributions for Northern Hemisphere winter 1979 using the LIMS data. (This work was in collaboration with Ellis Remsberg of NASA Langley Research Center.) The potential vorticity fields were used as a basis for definition of the area occupied by the polar vortex (a region of small mixing) and the subtropical "surf-zone" (a region of rather rapid meridional mixing). He found that the area of the polar vortex shrinks rapidly prior to a sudden stratospheric warming, consistent with the idea of a "preconditioning" of the flow as a necessary condition for such warmings. Similar signatures seem to be associated with the ozone and water vapor fields. This work is currently being prepared for publication.

#### (iv) General circulation modeling

With partial funding from the NSF work was begun in collaboration with Dr. B. Boville at NCAR on the development of



a version of the NCAR spectral GCM that will have about 36 levels with the top level in the lower mesosphere. Thus, the stratosphere will be resolved with about a 2 km vertical resolution. In order to develop this model it has been necessary to recode a number of the program modules in order to switch from the terrain following "sigma" coordinates to a hybrid vertical coordinate system that is terrain following near the ground, but becomes an isobaric system in the stratosphere. This is necessary to avoid severe geometrical distortions in the stratosphere when sigma coordinates are used over many scale heights. The new model is currently being debugged and work will continue under the new grant.

#### C. Bibliography (Publications supported by NAG2-66)

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